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truck traffic from this route. Further observation seems to indicate that all this pumping action was thereby eliminated.

This truck traffic was rerouted over U. S. 12, which is a 20-foot cement concrete pavement eight years older than the pavement on U. S. 20. After several months, a short section of this road began to show signs of similar failure. Investigation revealed that this was due to the same cause and, further, that the subgrade soil was of the same general character as that underlying the pavement on U. S. 20 where the first failures occurred. This fact was later confirmed in a study of a soil map of Porter County. From this it would seem that the subgrade is a major factor to be considered in combating this source of pavement failure.

During the past year a careful check has been made on all the roads in our district subjected to this type of traffic in order to determine the prevalence of this condition. We found that practically all of U. S. 6, U. S. 41 near Morocco, a long section of the new dual-lane pavement on U. S. 30 from U. S. 41 to a point just east of Valparaiso, and a short section of U. S. 30 near Plymouth showed signs of pumping, although not to the point where pavement failure resulted. An experimental section of U. S. 30, located approximately one mile east of Schererville, which was constructed with a sand cushion under the slab in 1937, was found to be particularly free from this trouble. This was interesting, especially in the light of the facts that the subgrade soil was the same as that with which we had our most serious trouble and that this road carried the same type of traffic. Assuming from this that the sand cushion was the preserving factor, all new rigid-type pavements constructed in this district during the past season have been placed on a sand cushion. It is too early yet to say that this is definitely the answer to this problem, but we believe it is a positive step in the right direction as far as new construction is concerned.

DRAINAGE OF HIGHWAYS AND AIRPORTS

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The technique of land drainage has been practiced for hundreds of years. The first tile drains in this country were placed in 1835. Since that time, many advancements have been made in drainage knowledge, and special techniques have been developed for many different drainage applications.

Comparison of Highway and Airport Drainage

Highway drainage and airport drainage are two of these applications which have their individual techniques, though they are similar in some respects. The problem in both cases is the removal of surface water resulting from rainfall and the removal of free ground-water from the soil beneath the structure.

It is usually considered most efficient to use separate systems for surface drainage and for subsurface drainage. This policy is common to both highways and airports. To require underdrains to carry storm-flow makes them unnecessarily large. Maintenance of critical underdrains is also increased by silting from storm water if the systems are combined.

Also similar in highway and airport drainage are the methods of subdrainage. Wherever seepage from the side of the construction area must be intercepted or existing ground-water removed, underdrains are used together with porous backfill material. The proper selection of this backfill material is an important consideration and will be mentioned again in detail.

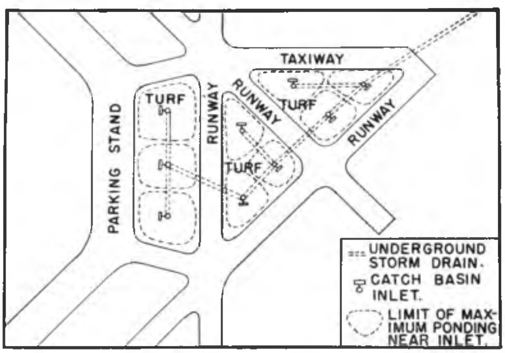

Fig. 1. Airport layout showing ponding areas.

The big difference between airport drainage and highway drainage is the problem of removing surface water. This difference arises from the wide variation in the types of area drained. A large commercial or military airport has an area to be drained equal to a 100 ft. right-of-way twenty miles long or more. This area has a run-off of 100% over a large portion. Heavy rains of short duration obviously produce tremendous quantities of water which must be removed immediately from critical areas to prevent danger and inconvenience to traffic. This must be done without the use of open ditches, which so easily solve the problem of surface water on highways. To provide sufficient storm drains and inlets to remove the water immediately from the field requires an enormous expenditure. In fact, one airport in Amsterdam employed 155 miles of drainage structures to accomplish this purpose. A simpler expedient and one more frequently used employs ponding areas. These areas, as shown in Fig. 1, are placed in the less critical, turfed sections between runways and taxiways. They store the storm water until the drain inlets at the center of the ponds can carry it away. Continuous operation of the critical areas of the airport is provided by this method.

Application of Pedology to Drainage

One of the recent advancements in drainage, applicable to both highways and airports, has been made through the study of pedology. Not a new subject in itself, pedology has only recently been used as an approach to engineering problems in soils. In the field of drainage it offers a special contribution through the use of soil surveys, which are prepared by the pedologists and which map the soil types of most of Indiana and a large part of the United States.

These surveys may be used in two ways to provide better-drained roads and airports. First, when locations are being selected for new highways and airports, the soil survey data present one of the easiest ways of selecting sites with good natural drainage or sites that will require a minimum amount of artificial drainage. U. S. Highways Nos. 24 and 30 east of Fort Wayne represent two excellent locations with respect to natural drainage. These routes were probably selected first by the old settlers of this country, who undoubtedly found, after many seasons of good and bad weather, that the ground there was uniformly the most stable and therefore the most reliable for traveling. Upon checking soil survey maps, it is now found that the routes they selected follow almost exactly the shoreline of the old glacial Lake Maumee. The soil there, a type known as Belmore (sometimes mapped as Fox), is a sandy gravel, well-drained, and an excellent road foundation. A short distance away, in the area between these roads and in the actual bed of the old lake, the soil is vastly different. Known as Fulton, the soil there is plastic, poorly drained, and unstable. Such excellent road location today does not have to be made by such a long, trial-and-error procedure. In the light of present scientific knowledge of soils, selections of this type and many others can be made in advance with a minimum of time and a minimum of effort.

Soil surveys may also be used to help determine proper drainage measures where the location is already known. For instance, when soils are encountered such as Plainfield, Buckner, and Calumet, which have excellent natural drainage, additional drainage measures are seldom required. Other soils—Brookston, Clyde, Toledo, and others—are almost impossible to drain internally, and roads built on them require raised profiles, porous insulation courses, or similar measures to insure their stability. Some soils suggest special drainage methods. For example, the soils known as Delphi, Homer, and Warsaw are among a large group of soils having a porous substratum of sand and gravel and an upper layer of relatively impervious soil. Heavy rains on these soils result in retention of surface water for a considerable period because water percolates slowly through the upper layer. (See Fig. 2.) When such conditions prevail for an extended period, the silty-clay soil becomes plastic and unstable, endangering the life of the pavement. The pavement shown in this picture has broken up excessively from pumping as a result of these conditions.

Fig. 2. Poorly drained highway with perched water-table.

A simple solution to the problem of drainage in these soils might well be drainage of the water into the sand strata. (See Fig. 3.) A trench through the upper layer, backfilled with porous material, would permit immediate disposal of surface water into the sand layer below. It is possible that the top layer might be so thick that it would be economically unfeasible to trench its entire depth. (See Fig. 4.) In this case, a more shallow trench with drains which empty into occasional drop-inlets penetrating the entire layer would solve the problem. This method should be used with caution and the drop-inlets designed with care, however, because of the danger of silting in the bottom of the inlets. It should be noted that, while the case just cited may seem very special, the types of soil having the characteristics described cover a million acres in this state.

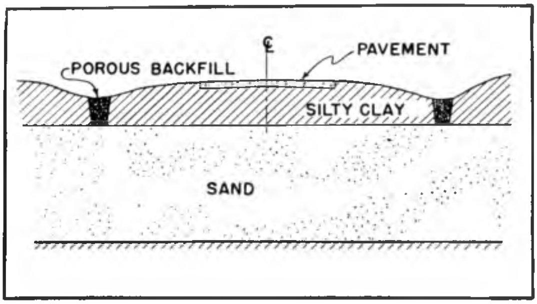

Fig. 3. Drainage correction for shallow clay layer with porous underlayer.

Thus, in many cases the advance information given by soil surveys would simplify drainage design for the engineer, allowing him to foresee drainage problems and to make preparations for them.

Filter Material for French Drains and for Porous Backfill Around Subdrains

The proper design of filter material for French drains and for porous backfill around drains is a problem that needs the closer attention of engineers. Silting of the drop-inlets and the drains indicated in Fig. 4 would be reduced to a minimum by proper design of the porous backfill around the drains. Silting of the French drains of Fig. 3 would also be minimized by the proper selection of filter material. In fact, improper design and selection of such material are undoubtedly responsible for the large number of failures of French drains, and are probably responsible for the prejudice against their use under any circumstances.

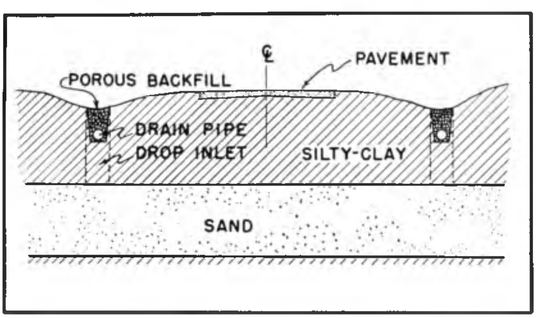

Fig. 4. Drainage correction for deep clay layer with porous underlayer.

Filter material serves two functions in drainage. It permits easy entrance of water into the drain, and it restricts the movement of fine particles from the surrounding soil, which might clog the drain and render it ineffective. Having these two functions to fill, a satisfactory filter material must satisfy two requirements. First, its permeability must be sufficiently greater than that of the surrounding soil so that it may remove water from that soil quickly and easily. Second, its gradation must be such that the fine particles of surrounding soil will not wash into the filter and cause it to become clogged. Thus, for any soil to be drained there is both an upper limit and a lower limit on the particle size or gradation of the proper filter to be used with it. This range would, of course, vary for different soils to be drained.

Though not too widely known to highway engineers, considerable research has been done to determine a criterion which would fix the range of suitable filter material for any given soil. Karl von Terzaghi was the first to give this matter consideration, although his primary interest was in dam filters, a similar problem. He developed a criterion for the satisfactory range of filter materials, and, though he never published it, it has received wide recognition in other publications.[1] Referring to the usual cumulative grain-size curve shown in Fig. 5, his criterion is based on the 15% size of the filter, which is that size next larger than 15% of the material. The criterion states that:

(*a*) The 15% size of the filter shall be at least four times as large as the 15% size of the surrounding soil. (This assures a filter permeability of about 16 times that of the surrounding soil.)

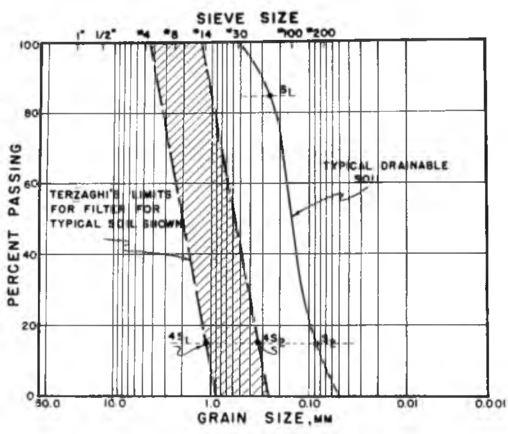

Fig. 5. Terzaghi's criteria for filter design.

(*b*) The 15% size of the filter shall be not more than four times as large as the 85% size of the surrounding soil. (This would prevent the fine particles of the surrounding material from washing through the filter.)

The first part of this criterion is purely arbitrary and was based on good judgment and experience. The other part, regarding the stability of the filter or its ability to withhold the fines of the surrounding soil, can be determined by actual tests. This part of the criterion has therefore been the object of study by other investigators since its original formulation. G. E. Bertram[1] ran a series of tests at Harvard in 1939 on various filters draining various gradations of "bases". He found that the filter was always stable when the ratio of its 15% size to the 85% size of the surrounding soil was less than six. Similar tests recently conducted at the U. S. Waterways Experiment Station[2] showed that the minimum value of this ratio for stability was five. The results of these three independent investigators are plotted in Fig. 6, which shows the very close agreement between them.

Other significant conclusions by the U. S. Engineers were that the grain-size curve of the filter should be approximately parallel to that of the surrounding soil in order to minimize the washing of fines into the filter, and that a well-graded filter is less likely to wash into drain-pipe openings than a uniform filter of the same average size.

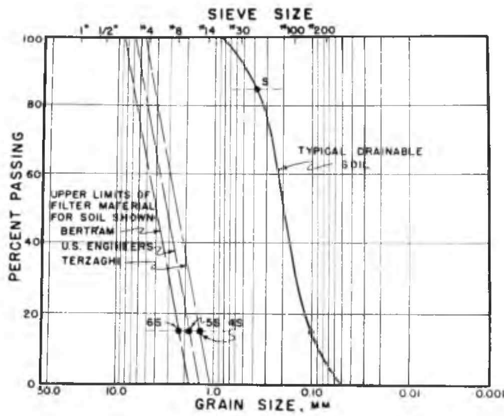

Fig. 6. Comparison of upper limits for filter material.

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[1] Bertram, G. E.—*An Experimental Investigation of Protective Filters*, Harvard University, 1940.

[2] "Investigation of Filter Requirements for Underdrains," *Technical Memorandum No. 183-1*, U. S. Waterways Experiment Station, Vicksburg, Miss., 1941.

Recent practice in many highway departments has been the use of large stones and short gradations for drainage filters. Not long ago, No. 2 aggregate was in common use in Indiana, and more recently No. 5 aggregate was widely used. Current practice is No. 7 aggregate, slightly finer than the No. 5. Fig. 7 shows how the gradations of these aggregates compare with the proper gradation of a filter for a typical Indiana silt. This comparison in itself is an indication of why many of the porous backfills and French drain installations using these materials were not successful. Not only are these aggregates far removed from the desirable gradation for a filter, but they are also much more expensive than many more easily available materials such as pit-run gravel, crusher-run stone and slag, and lake sands.

To make a similar comparison with actual tests, a typical pit-run gravel and a No. 5 aggregate were obtained for filter materials, and a typical silt from LaPorte, Indiana, was used as the soil being drained. A number of permeameter tests using these materials were run at the Joint Highway Research Project.[3] It was found that the pit-run gravel was satisfactory under hydraulic gradients as high as ten, and under the same gradients, the No. 5 aggregate failed because of silting.

Location and use of natural materials that fill the proper requirements would not only result in a saving in drainage costs but also would increase the effectiveness of drainage installations.

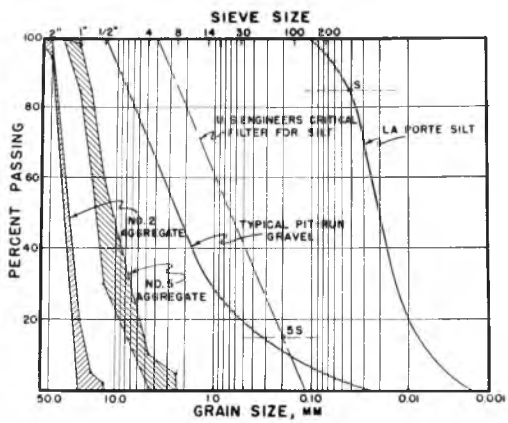

Fig. 7. Comparison of Indiana aggregates with filter limits.

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[3] McAlpin, G. W.—"Drainage of Highway Subdrains," *Unpublished Progress Report, Joint Highway Research Project,* 1941.